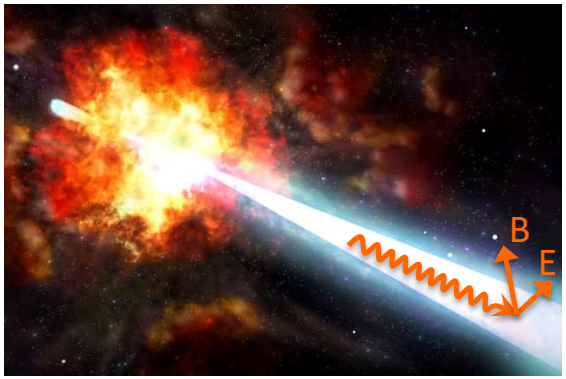
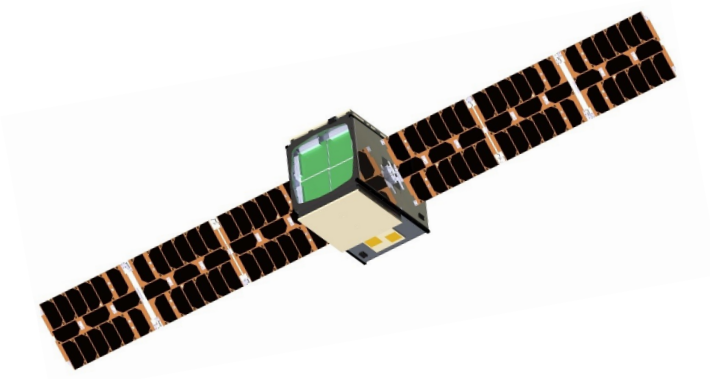
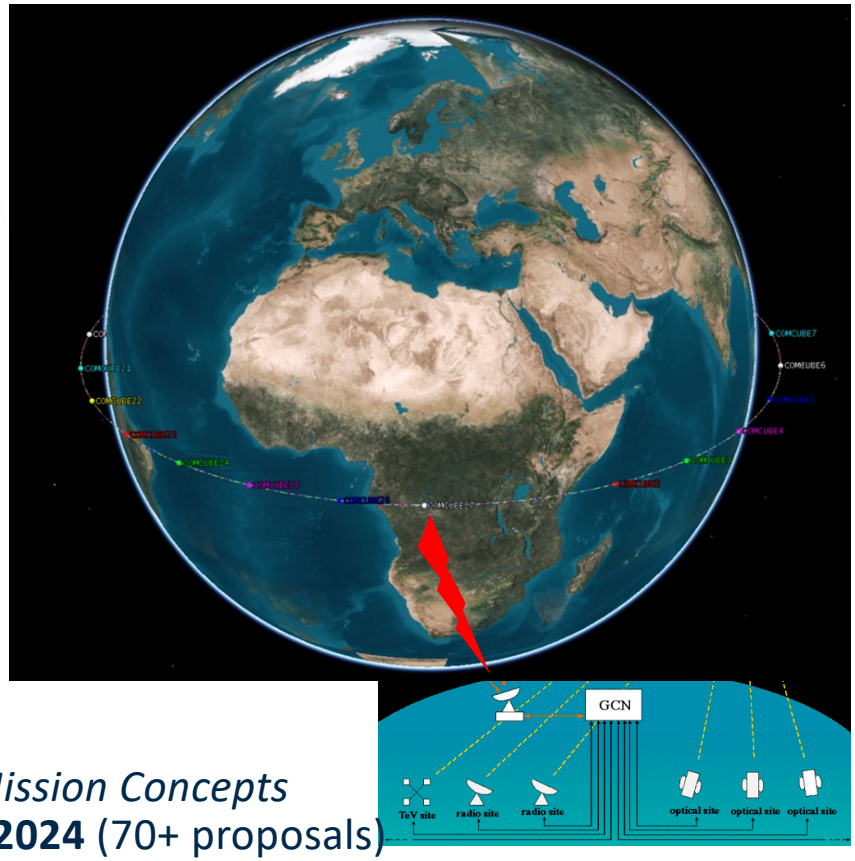
COMCUBE-S: a constellation of CubeSats for gamma-ray burst polarimetry







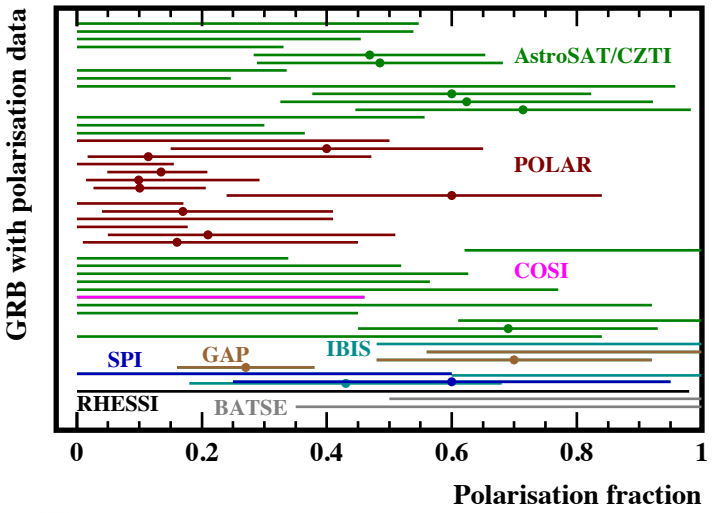
- Main science goal: understand the physics of gamma-ray burst jets from **polarisation measurements** to be able to **use GRBs as standard candles in cosmology**
  (Nathan Franel's CNES / IN2P3 PhD thesis 2022 - 2025)
- Enabled science: continuous monitoring of the gamma-ray sky for **multi-wavelength & multi-messenger time-domain astronomy**
  (CNES / IN2P3 PhD thesis 2025 - 2028)
- Proposed to ESA in Feb. 2023 in response to a call for *Innovative Mission Concepts Enabled by Swarms of CubeSats* – **Selected after a Phase 0 in Apr. 2024** (70+ proposals)
- Studied at ESA's CDF in June 2024; **9-month non-competitive Phase A starting** in February 2025 (KO date TBC)
- Collaboration: **UCD** (Dublin), **IJCLab**, CEA-Irfu, KTH (Stockholm), AAC Clyde Space (Glasgow)

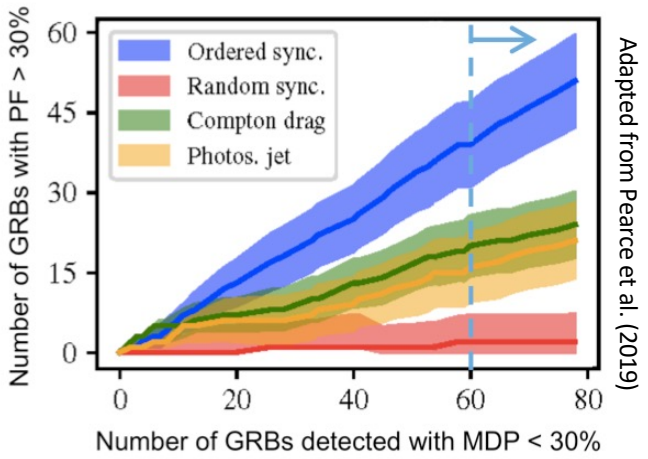
Gamma-ray burst polarimetry

- **Spectral and light-curve information insufficient** for understanding the plasma composition, the magnetic field origin and the main energy dissipation processes in the **ultra-relativistic jets of GRBs**
- **Linear polarisation of GRB prompt emission** can be a powerful diagnostic, but no consistent picture yet available
- COMCUBE-S main science requirement: **detect 60+ GRBs with an Minimum Detectable Polarisation < 30%** - can be met with a **2-year science operation mission in the baseline configuration** (27 satellites on an equatorial orbit at 500 km altitude)
- **Time-resolved polarimetry in more than 8 GRBs per year**

Annual rate of GRB detection with an MDP < 30% (© Nathan Franel)

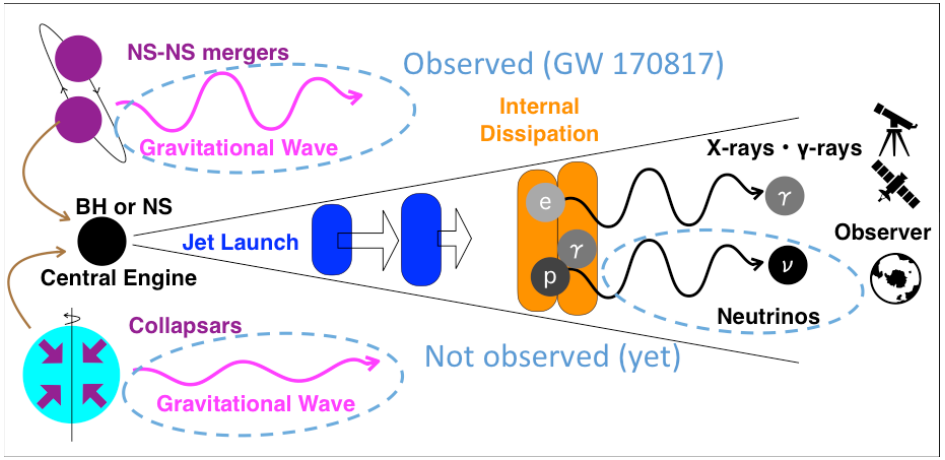
	i = 0°	i = 45°	i = 97.4° (SSO)
All S/C working	35.6	28.2	24.9
1 S/C off	34.9	27.3	23.5
2 S/C off	33.0	24.8	21.7
3 S/C off	28.7	21.5	19.9
5 S/C off	18.5	14.1	11.6



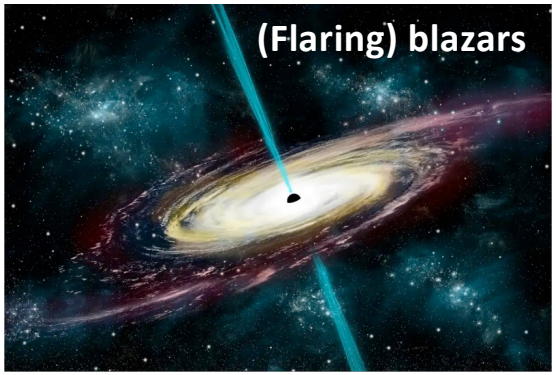


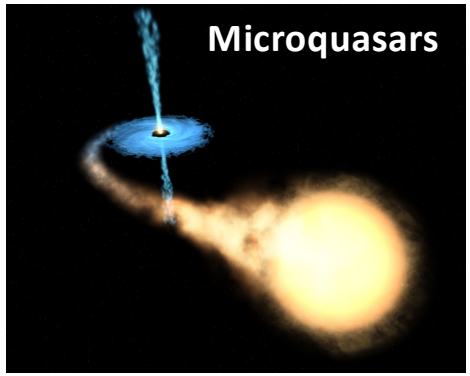
Multi-wavelength and multi-messenger observations for time-domain astronomy

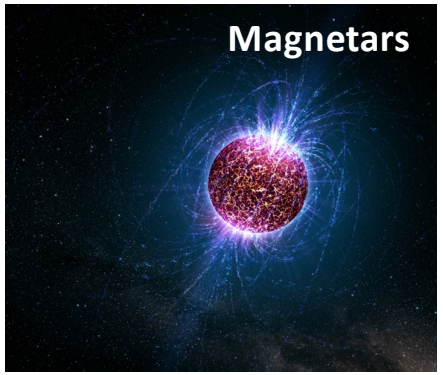
- **Predicted GRB detection rate > 500 yr $^{-1}$** (© Nathan Franel) more than any other existing or planned mission
- GRB alert notification with source position **within 30 s after trigger ⇒ multi-wavelength follow-up observations** for host galaxy detection (=> redshift) and afterglow emission studies
- Search for an electromagnetic counterpart to **gravitational waves** detected with LIGO/Virgo/KAGRA
- … and **high-energy neutrinos** detected with IceCube and KM3NeT (⇒ extragalactic cosmic rays)

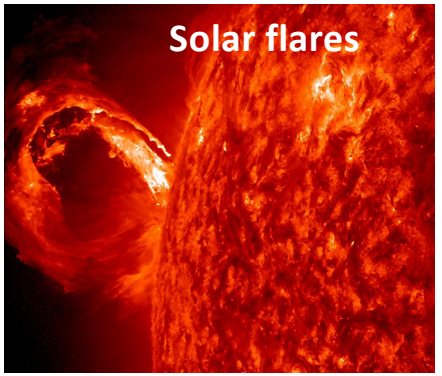


- **Other transient sources** detected by COMCUBE-S: flaring AGNs, microquasars, magnetars, solar flares etc. **real-time classification** and transmission to the GCN for multi-λ follow-up observations with the **FINK broker**



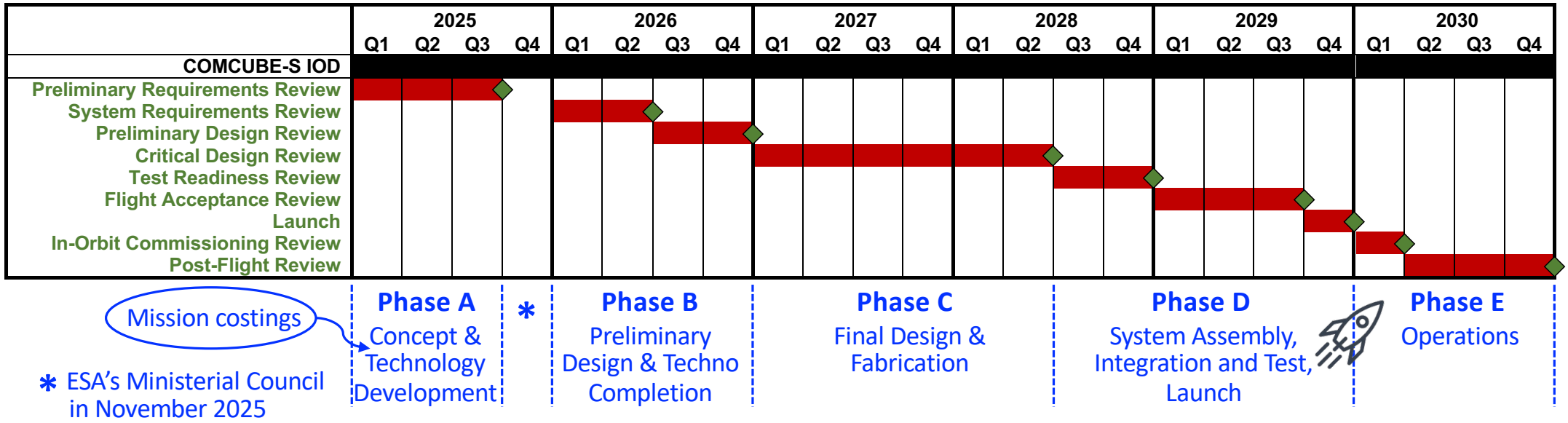






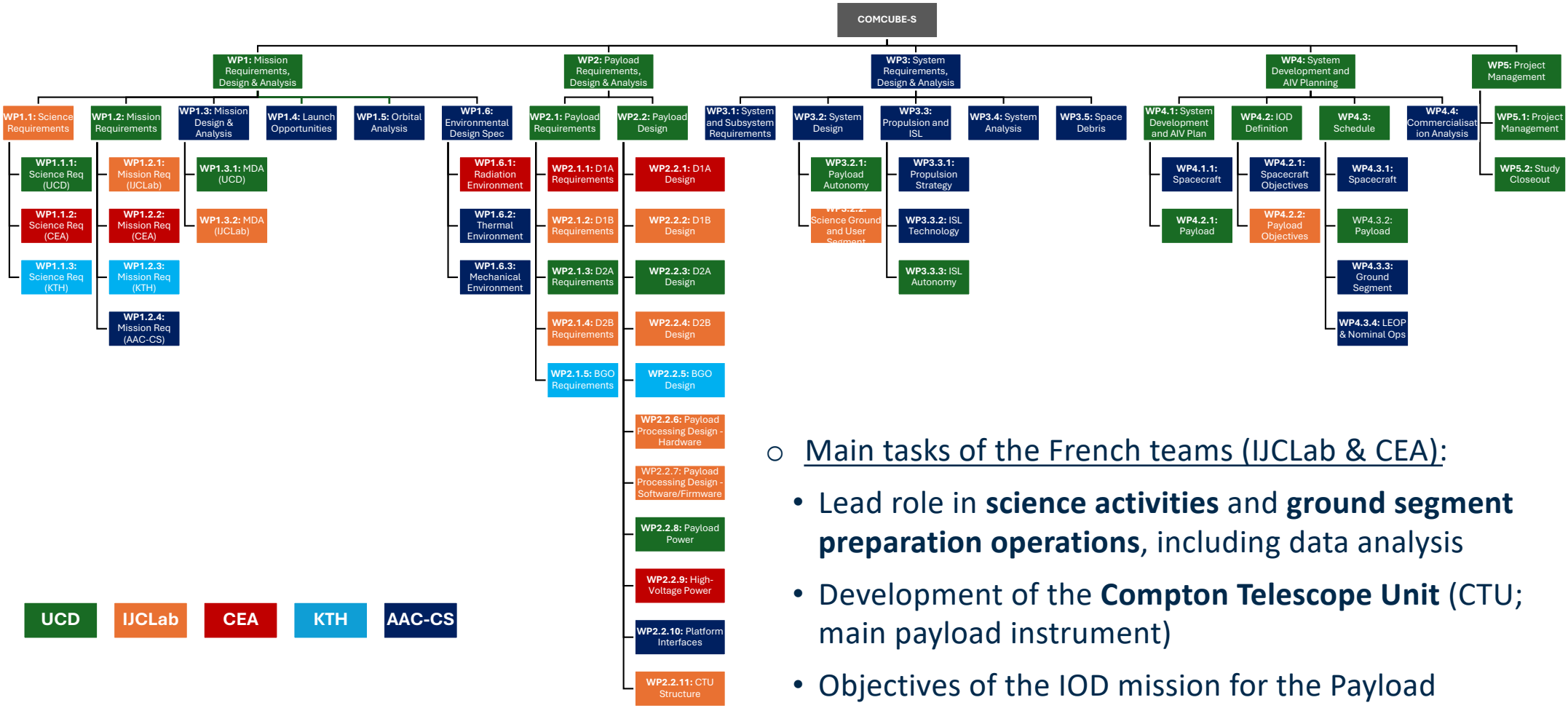
COMCUBE-S mission timeline

- In-orbit demonstration (IOD) mission with two CubeSats to be **supported by ESA's General Support Technology Programme** (GSTP) before the full swarm mission
- **Preliminary schedule of the IOD mission**:



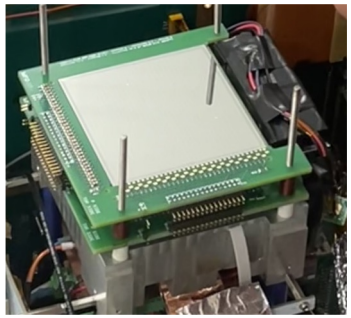
- Two Payload Flight Models to be delivered to AAC Clyde Space (Glasgow) for system integration in Jan. 2029
- Full swarm mission with 27 CubeSats could be expected for 2033 (TBC)

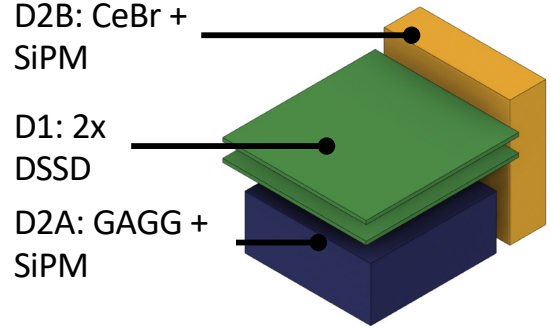
Phase A – Work Breakdown Structure



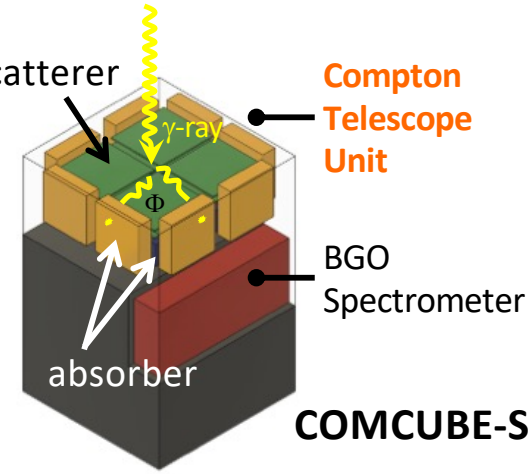
- Main tasks of the French teams (IJCLab & CEA):
  - Lead role in **science activities** and **ground segment preparation operations**, including data analysis
  - Development of the **Compton Telescope Unit** (CTU; main payload instrument)
  - Objectives of the IOD mission for the Payload

COMCUBE-S CubeSat payload

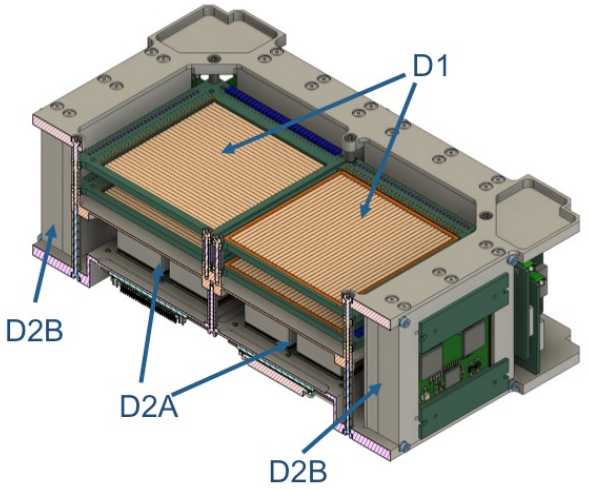


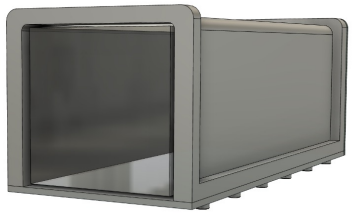


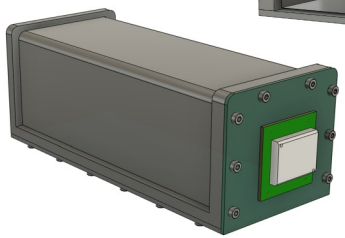
Payload in COMCUBE Balloon



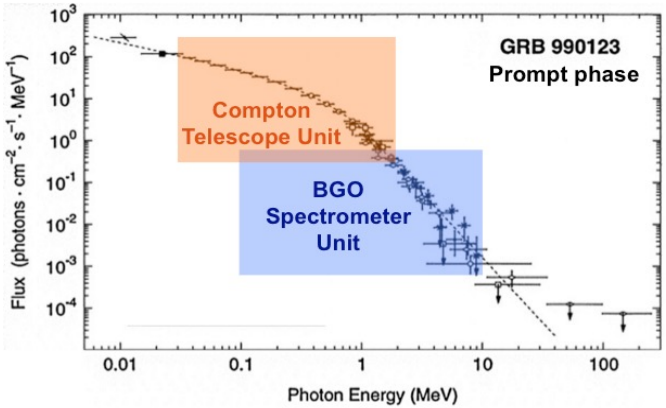
COMCUBE-S

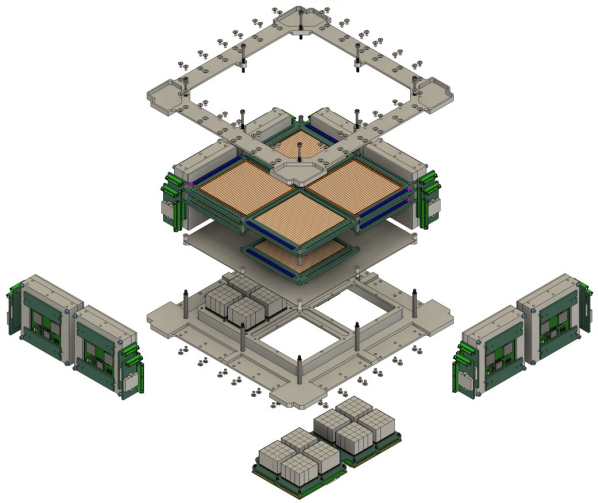






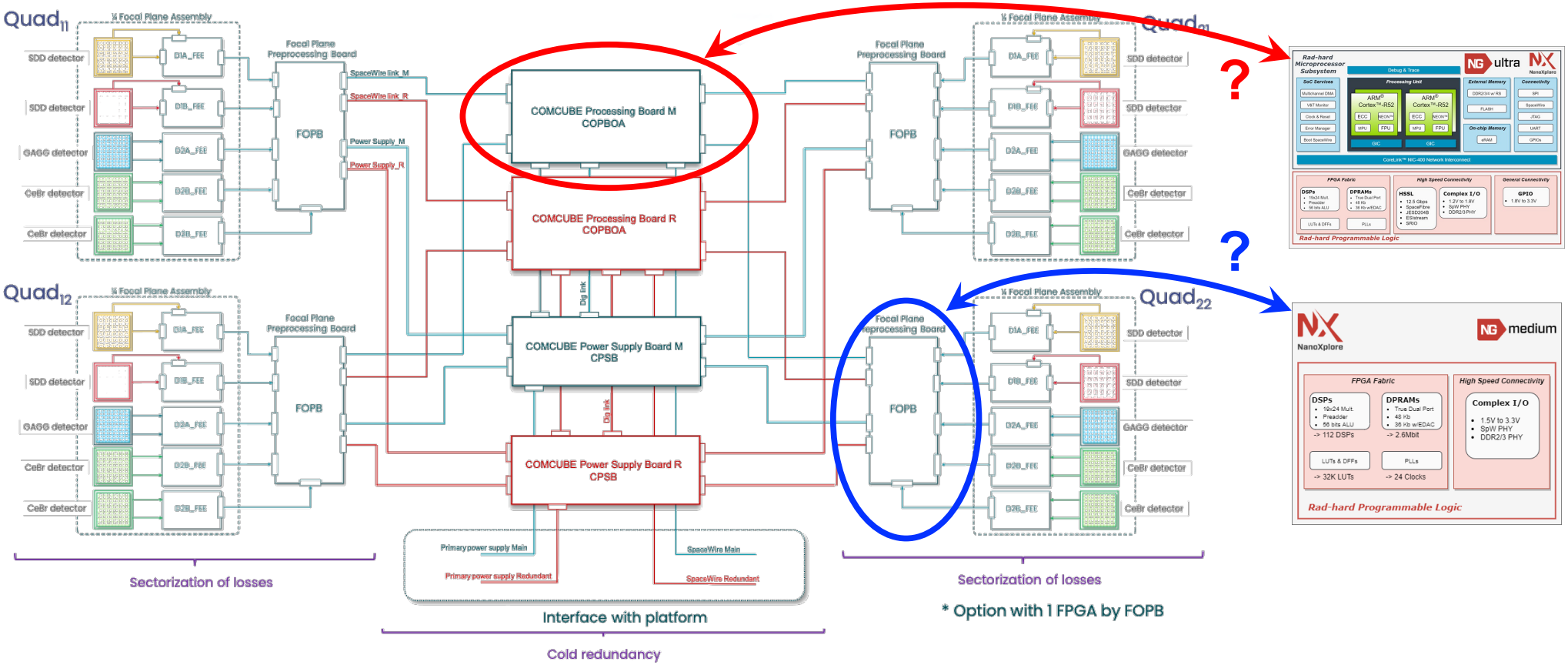
BGO Spectrometer





- Auxiliary BGO Spectrometer
  (50 x 50 x 150 mm^3) extending spectral range and sensitivity…

CTU preliminary electronical architecture



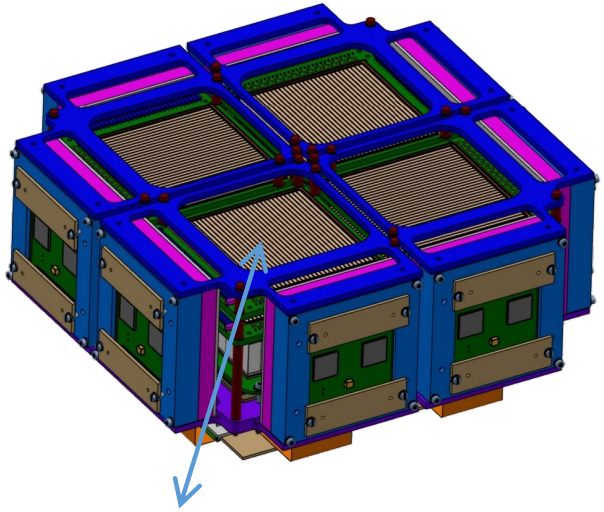
- Introduction to **KOSMOS (LVCUGen)** by Thomas Delmas on 22 Jan 2025
- **Potential excellent synergy with projects of the DTN/TVO/LV department** (KOSMOS + NG-ultra, SWARM…)

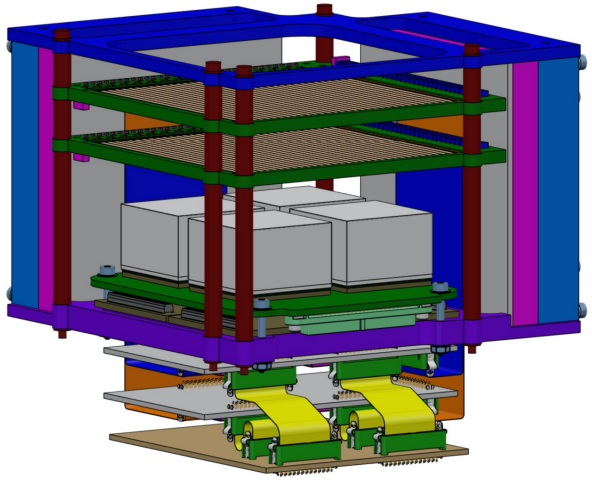
Technology Readiness Levels for the Compton Telescope Unit

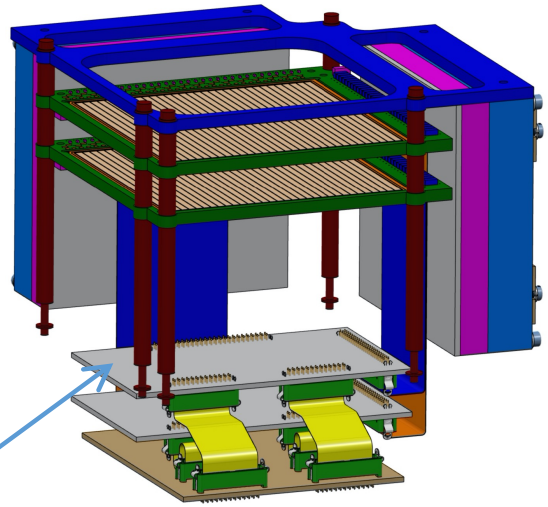
Module	Detector	Item	TRL	Comments
CTU	D1	DSSD	5	BB7 detector not yet qualified for space, but several other products from Micron are at TRL 9
		Carrier PCB	4	Modification of the design used in the COMCUBE prototype for the balloon flight tests
		Flex Cable Interface	3	Commonly used by Micron to attach DSSDs to readout electronics, but not tested yet
		VATA460.3 ASIC	9	Flight heritage with the High-energy Electron exPeriments (HEP) on the Arase satellite
		IDeF-X ASIC	9	Flight heritage with two instruments of the Solar Orbiter mission
		Front-End Board	4	Modification of the FEBs used in the COMCUBE prototype for the balloon flight tests
	D2	SiPM Array	5	Flight heritage of the SiPMs with the GMOD payload on EIRSAT-1, modification of the array
		Optical Interface	9	Flight heritage with the GMOD payload on EIRSAT-1
		GAGG Scintillator	5	GAGG is at TRL 9 with the GRID mission, but no flight heritage of the segmented configuration
		SIPHRA ASIC	9	Flight heritage with the GMOD payload on EIRSAT-1
		Carrier PCB	4	Modification of the design used in the COMCUBE prototype for the balloon flight tests
	D2B	SiPM Array	5	Modification of the design used in the COMCUBE prototype for the balloon flight tests
		$CeBr_3$ Scintillator	5	Similar in design to the $CeBr_3$ scintillator flown on EIRSAT-1 / GMOD
		Citiroc 1A ASIC	9	Flight heritage with the CSES Chines-Italian Space mission
Payload Processor		NG-Medium & Ultra	5	Based on space qualified active components
Payload Power Conditioning and Distribution			-	New development for COMCUBE-S, built on experience with the COMCUBE prototype

- Most critical aspect of CTU development: **mechanical and electronic integration of the Si detectors in the CubeSat ⇒ early development models** to reach TRL ≥ 6 at the end of phase B (Q4 2026)

Intégration des détecteurs Si dans le CTU

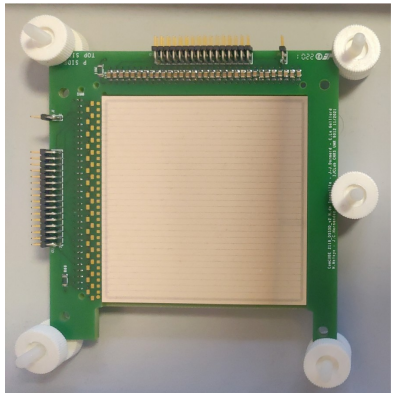






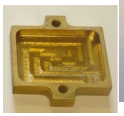
Détecteur BB7 (DS)-1500 (COMCUBE Ballon)

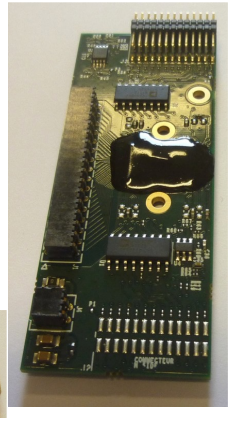
Electronique frontale IJCLab (COMCUBE Ballon)



- **Détecteur Si double face à pistes** (32+32), d'épaisseur 1.5 mm et de pitch 2 mm
- **PCB détecteur** avec couplage AC de l'électronique de lecture et connecteurs coudés (signaux + HV)

⇒ **Nouveau PCB pour COMCUBE-S**

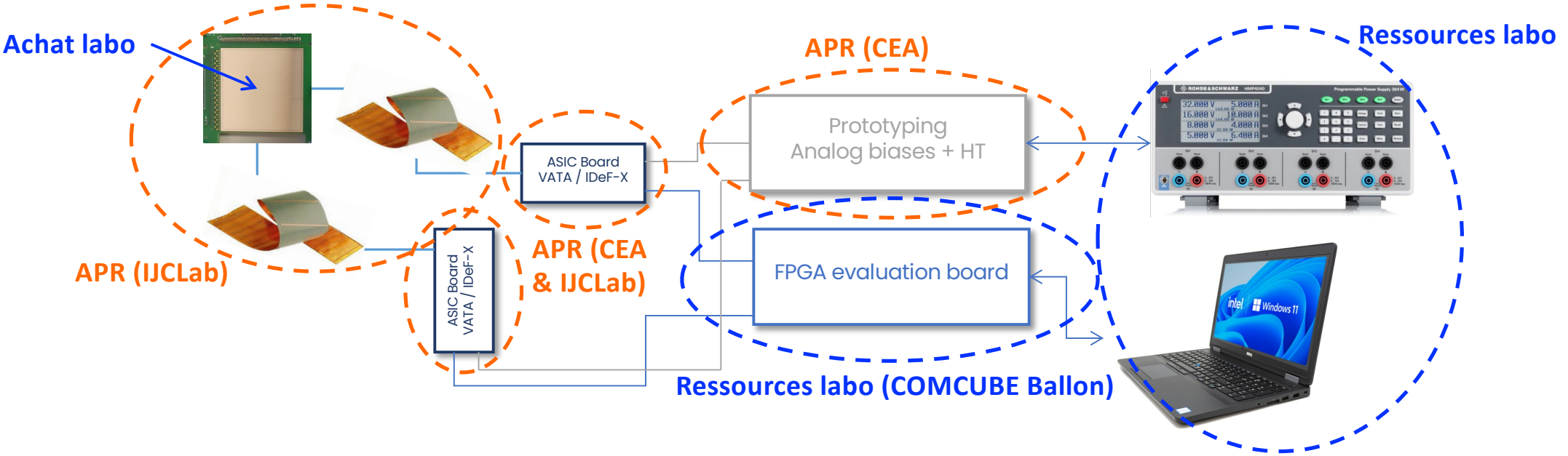




- ASIC VATA460.3 : 32 pré-amplis de charge + 32 ADCs (1 face du BB7)
- Carte FEB développé à IJCLab

⇒ Remplacement de certains composants pour la **spatialisation** (connecteurs…), adaptation aux **contraintes mécaniques**

APR COMCUBE Silicium : tâches à accomplir

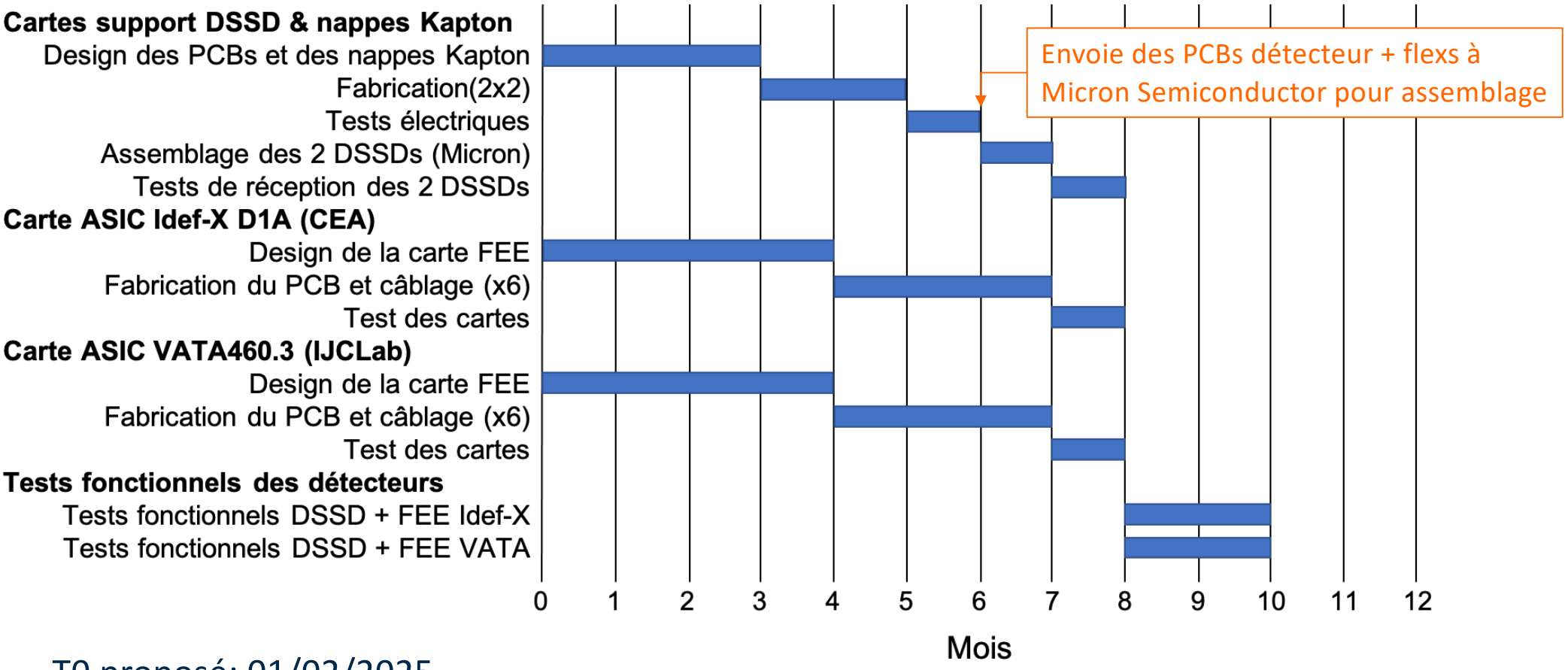


- **Réalisation de 2 chaines de détection pour les tests fonctionnels DSSD + cartes d'électronique frontale**, l'une avec des cartes ASIC IDeF-X (CEA) l'autre avec des cartes ASIC VATA460.3 (IJCLab)
- Etude de la connexion entre le PCB détecteur et la carte ASIC (cruciale pour les perfs détecteur) : (i) **PCB flex-rigide** avec une couche flexible intégrée au PCB pour la transmission des signaux jusqu'à la carte ASIC, ou (ii) nappe de câbles flexibles fixée au PCB **par brasage à la barre chaude**
- **Modification des cartes ASIC IDeF-X et VATA460.3** pour les contraintes mécaniques et la spatialisation

APR COMCUBE-Si : Travaux CEA/IRFU

- Suite aux travaux déjà menés qui ont permis de réaliser le DSSD qui a volé sur le vol ballon CNES/TRANSAT en juin dernier,
- Et conformément aux spécifications qui seront dérivées lors de la Phase A ESA COMCUBE-S en 2025, Les travaux menés au CEA-Irfu seront:
  - Redesign de la carte d'électronique frontale (FEE) autour de l'ASIC IDeF-X
  - Réalisation d’un prototype de la carte d’alimentation HV des DSSD
  - Construction d’une chaîne de détection DSSD/FEE-ASIC/Acquisition/HV
  - Tests fonctionnels des chaînes de détection en partenariat avec IJCLab

APR COMCUBE Silicium : calendrier de réalisation



T0 proposé: 01/02/2025

APR COMCUBE Silicium : budget & ressources humaines

- Le financement par l'ESA de l'étude de Phase A ne couvre pas la réalisation de modèles de développement
- Détecteurs DSSD BB7 (15 k€) achetés à Micron Semiconductor par des financements labo (IJCLab + CEA)

Petite mécanique pour les bancs de test…

BUDGET DEMANDE AU CNES PAR IJCLab	
LISTE DU MATERIEL INVENTORIABLE	Valeur d'achat € HT
Cartes support DSSD et nappes Kapton associées (2 pour chacune des 2 solutions envisagées, 1800 €	7 200.00
Cartes ASIC VATA460.3 (x6, 2300 € pièce)	13 800.00
Petit matériel	3 000.00
TOTAL H.T.	**24 000.00**

- **Equipe IJCLab** (ETP sur 10 mois)
  - Responsable scientifique (0.3 ETP) : VT
  - Responsable technique & mécanique (0.2 ETP) : Christine Le Galliard
  - Equipe électronique (1.0 ETP) : **Christophe Beigbeder**, Arnaud Saussac, Jimmy Jeglot, Beng-Yu Ky
  - Equipe scientifique et instrumentation (1.1 ETP) : **Nicolas de Séréville**, Mariya Georgieva, Jean Peyre, Joseph Mangan (post-doc) & Nathan Franel (doctorant)
  - Equipe informatique (0.1 ETP) : **Nicolas Dosme**, Vincent Lafage, Matias Vecchio (apprenti)

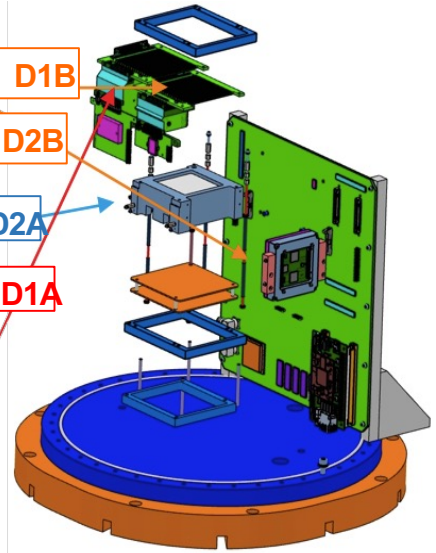
APR COMCUBE-Si : Travaux CEA/IRFU

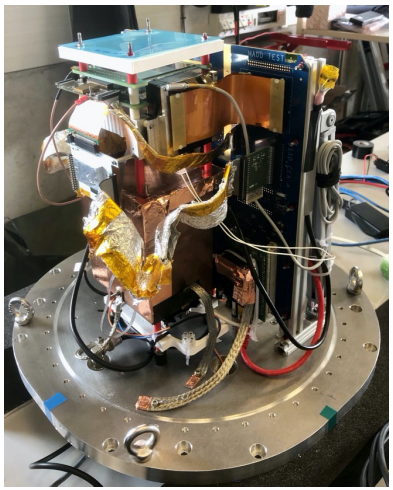
- Le budget demandé est de 18 k€ (50/50 donc 9 k€ pour le CNES):
  - 2 cartes FEE IDefX : 2 x 5 k€
  - 2 cartes HV : 2 x 4 k€

- Le personnel CEA sera composé de ~ 1.0 ETP sur 10 mois (30% Philippe Laurent, 10% Aline Meuris, 10% Eric Doumayrou + 10% Marin Prieur + 5% Olivier Gevin + 30% alternant).

Extra slides

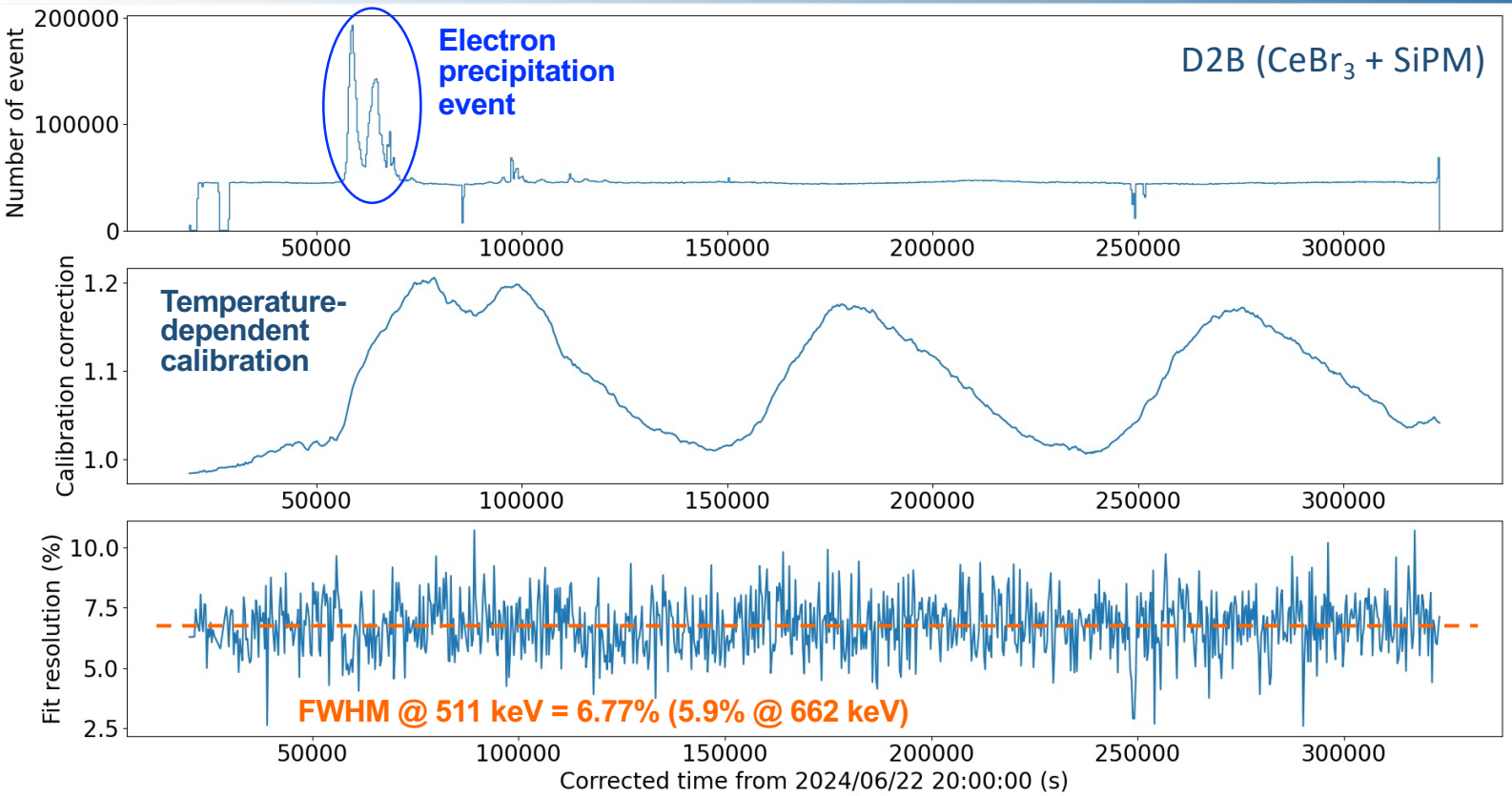
Qualification of a CTU prototype in stratospheric balloon flights

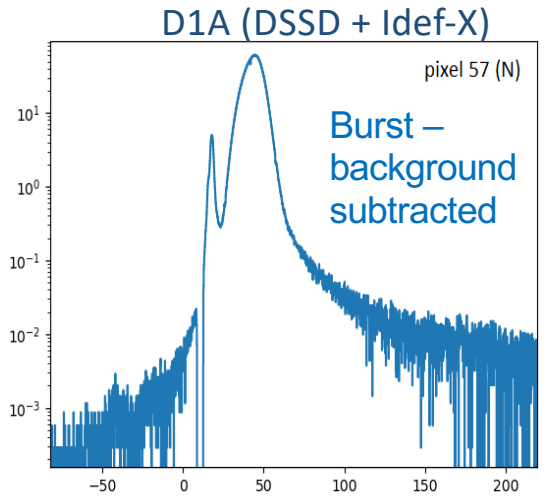


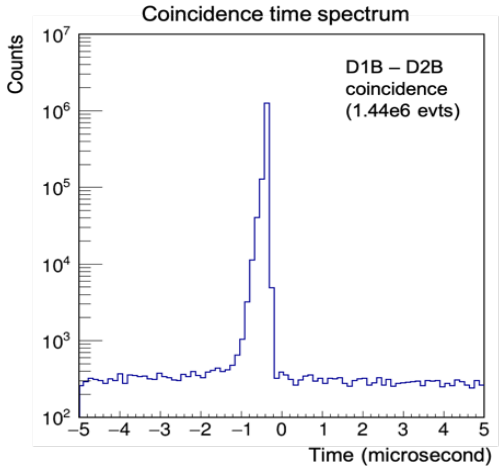


- **COMCUBE prototype** developed by IJCLab, CEA & UCD: ~ 1/4 of Compton Telescope Unit
- **Stratospheric balloon flights**: PRE-TRANSAT from Timmins (Canada) on 27 Aug. 2023, TRANSAT from Esrange (Sweden) to Baffin Island (Canada) on 22-26 June 2024 (3 days and 17 h): **first transatlantic flight operated by CNES**

TRANSAT flight data analysis (Nathan's work, in progress)







- Time-dependent (temperature-dependent) calibration of detectors, coincidence events between all detectors, reconstruction of Compton events for **imaging** and **polarisation measurement** of the Crab pulsar and nebula (?)